Mapping World Scientific Collaboration on the Research of COVID-19: Authors, Journals, Institutions, and Countries

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Abstract

The COVID-19 (2019 novel Coronavirus) is the most widespread pandemic infectious disease encountered in human history. Its economic losses and the number of countries involved rank first in the history of human viruses. After the outbreak, researchers in the field of medicine quickly carried out scientific research on the virus. Through a visual analysis of relevant scientific research papers from January 1st to April 1st, 2020, we can grasp the worldwide scientific research cooperation situation of 2019-nCoV research and reflect the international collaboration in combating the pandemic. To this end, 415 papers indexed in Thomson Reuters's Web of Science were studied to provide a visualized description of scientific collaborations across the world by multiple levels, including author level, journal level, institution level and country level.

1. Introduction

The trend of globalization has become a basic feature of the current era. With international affairs being closely linked and the high population mobility, public health security becomes a hidden danger that cannot be ignored. Severe Acute Respiratory Syndrome (SARS) in 2003 was the first global public health emergency of the 21st century. The sudden outbreak of COVID-2019 at the beginning of 2020 poses a major threat to the health and safety of people in China and around the world, and has had a huge impact on all sectors of society. On January 30, 2020, in view of the worldwide impact of novel Coronavirus pneumonia (COVID-19), WHO declared the COVID-19 as an "international public health emergency". As of April 3rd, 2020(Beijing time), real-time statistics from Johns Hopkins University showed that the number of confirmed COVID-19 cases worldwide has exceeded 1 million, and the number of deaths has reached 51,485. The data is still on the rise. With the spread of COVID-19 around the world, scholars and experts in the field of scientific research and health from all around the globe have paid great attention to it. Relevant scholars started to study related fields at the early stage of the pandemic. Due to Apr 1st, 2020, 415 papers related to the subject have been included in the core journals of WOS. The objective of this study was to provide the global description of collaboration behaviors across multiple collaboration types including authors, journals, institutions and Countries within the three months following the initial outbreak of COVID-19.

2. Scientific Collaboration Networks

Scientific collaboration is referred to as one of the defining features of "Big Science" and one of the results of the "professionalization of science"[1]. Scientific collaboration networks of authors are considered connected if they have co-authored a paper. The coauthors' institutions and countries also connect due to authors' collaboration[2]. Scientific collaboration networks of journals can be determined based on citing-cited relationships between publications. The citing-cited relationships connect two journals[3]. The benefits and merits of research collaboration include: sharing and transferring knowledge and research equipment, connecting scholars to a large scientific network, expediting the research process, and increasing the visibility of

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articles [4-10] The development of modern science is characterized by significant differentiation and integration, which forces researchers to gradually abandon the original mode of individual research during the process of scientific research. To understand the situation of international cooperation in scientific research under the "international public health emergency", this study focuses on the current outbreak of COVID-19, taking WOS core periodical database as the data source, using VOSviewer and Hiscite to conduct a bibliometric analysis of papers with the theme of COVID-19 published for nearly 3 months. We constructed collaboration graphs for authors, journals, institutions and countries in the medical field. Through the analysis of the international scientific research collaboration during the pandemic, we provided a global description of international scientific research collaboration when the world meet the COVID-19, an "international public health emergency".

3. Date source

The study analyzed 415 documents from Web of Science (WoS) core collection. The type of the document is article. Since the outbreak of the global COVID-19 public health emergency, it has rapidly attracted extensive attention from scholars all over the world. Since the World Health Organization and relevant departments in China did not adopt a unified standard name for "COVID-19" at the early stage of the pandemic, the academia did not form a unified name for it. On this basis, in order to make this study more convincing and ensure the rigorousness of scientific research, we selected the top 7 keywords from the list of keywords recommended by the Novel Coronavirus study related resources in the library of Wuhan University. The retrieval model is TS= ("COVID-19" OR "2019-nCoV" OR "nCoV-2019" OR "2019 Coronaviruses" OR "2019 novel Coronavirus" OR "Novel coronavirus" OR "Novel coronavirus pneumonia") [11]. The time span was customized as 2020-2020, and the retrieval time was April 1, 2020. We filtered out papers which neither focus on the virus itself nor make medical contribution to combat viral infections but contained keywords related to COVID-19. 415 papers were finally obtained.

4. Authors' Collaboration

Authors' collaboration or co-authorship networks document scientific collaboration through published articles, where nodes are authors and a link represent the fact that two authors have written at least one paper together. Co-authorship networks are thus undirected networks[12]. After the outbreak of COVID-19, authors in the field of medicine conducted a global scientific research on the rapid response to public health emergencies. The figure 1 shows the size of collaborations by authors of 415 papers. There are 109 papers with only one author, accounting for 26%; 54 papers co-authored by two authors, accounting for 13%; 48 papers co-authored by three authors, accounting for 12%; 204 papers co-authored by three or more authors, accounting for 49%. This analysis shows that the majority of papers (74%) published within the 3 months following the initial COVID-19 outbreak were multi-authored.

In order to display the current authors' collaboration for pandemic research, and then find the important author in the field of pandemic research group, we used VOSviewer to make a visualized analysis.

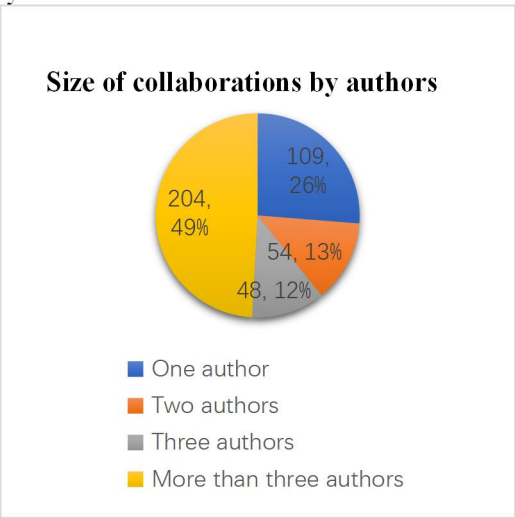

Figure1 Size of collaborations by authors

We chose the co-authorship analysis and drew a knowledge map of the authors' collaboration as shown in Figure 2. The size of the node depends on the number of papers published by this author. The bigger the node is, the more papers published by this author in the group. The links represent collaboration between authors. The thickness of a line depends on the strength of the collaboration between two authors. Different colors represent different groups of authors. Through the co-authorship analysis of authors, the distribution of authors with important research in the field of pandemic research can be seen.

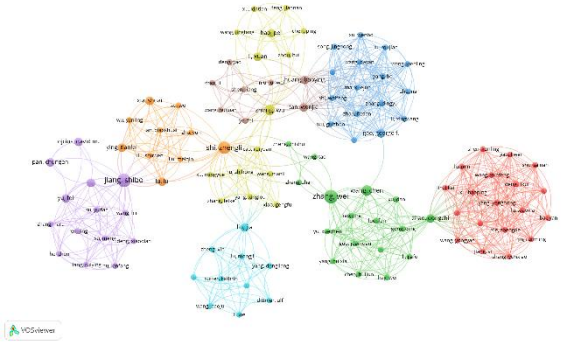

Figure2 Authors collaborative cluster map

This study selected the top 25 authors of each paper and there were 1629 authors contained by 415 papers. VOSviewer was used to perform a cluster analysis of authors' collaboration. Figure 2 displays research groups that have a connection with another group. If a research group has not collaborated with another research group, it will not appear in Figure. From the perspective of the collaborative network in Figure 2, Chinese authors have formed 8 obvious connected research groups within the 3 months of COVID-2019 outbreak. These research groups are shown as clusters in Figure 2. The purple research group indicates authorship by Jiang Shibo; the yellow research group indicates authorship by Shi Zhengli and Lu Lu; the brown research group indicates authorship by Huang Baoying and Tan Wenjie; the red research group indicates authorship by Zhong Wu; the bright blue research group indicates authorship by Liu Jia; the dark blue research group indicates authorship by Gao George F.; the green research group indicates authorship by Zhang Wei, Wang Chen and Zhao Dongchi.

It can also be found from the figure 2 that Jiang Shibo, Shi Zhengli, Zhong Wu, Huang Baoying, Liu Jia, Zhao Dongchi, Wang Chen, and Gao George F. act as bridges between different research groups in the authors' collaboration network. Bridging is one of the potential roles of a core author. People whose networks bridge the structural holes between groups have an advantage in detecting and developing rewarding opportunities. Information arbitrage is their advantage. They are able to see early, see more broadly, and translate information across groups. These authors are core authors in the collaboration because they connected different research groups and make them a whole network[13].

In order to study the influence of author collaboration on the number of papers and times cited, we make three ranking lists for authors of the 415 papers. We rank the top 5 authors by the number of their papers published from Jan 1st 2020 to Apr 1st 2020 in Table1, top 5 authors by times cited in Table2, and top 5 authors by the number of their collaborators in all of their papers in Table3. The authors with the same number of papers, times cited and number of collaborators may be co-authors of the same article or several papers. As shown in Table 1, the top five authors have many collaborators except the first author who did not collaborate with others. There are no Chinese authors in the top 3 of Table 1, but the top 3 authors of Table 2 are all Chinese. Although they have published only one or two papers, they are highly cited. Comparing Figure 2, we can find the top 3 authors, Gao George F., Huang, Baoying and Tan Wenjie act as bridges in the whole collaboration network. They are core authors in the research groups and are very influential during the outbreak of COVID-19. As shown in Table 3, we ranked authors by the number of collaborators. It seems the top 5 authors in Table 3 received a relatively high times cited and published more papers. In order to study the relationship between number of collaborators, times cited and number of papers, we made a Pearson correlation analysis based on the data of 1629 authors[14]. We imported the data into SPSSAU[15]. The result of the correlation analysis is shown in Table 4.

Table1 Author list ranking by number of papers

Rank	Author	Number of papers	Times cited	Number of collaborators
1	Mahase, Elisabeth	13	12	0
2	Akhmetzhanov, Andrei R.	7	18	57
	Linton, Natalie M.	7	18	57
	Nishiura, Hiroshi	7	18	57
3	Hayashi, Katsuma	6	18	55
	Jung, Sung-mok	6	18	55
	Kinoshita, Ryo	6	18	55
	Kobayashi, Tetsuro	6	18	55
	Yang, Yichi	6	18	55
4	Drosten, Christian	5	69	66
	Yuan, Baoyin	5	18	45
	Jiang, Shibo	5	10	29
	Zhang, Wei	5	8	17
5	Zumla, Alimuddin	4	24	25

Table 2 High cited author list

Rank	Author	Number of papers	Times cited	Number of collaborators
1	Gao, George F.	2	111	20
2	Huang, Baoying	2	87	24
	Tan, Wenjie	2	87	24
3	Ii, Xingwang	1	86	17
	Lu, Roujian	1	86	17
	Ma, XueJun	1	86	17
	Niu, Peihua	1	86	17
	Shi, Weifeng	1	86	17
	Song, Jingdong	1	86	17
	Wang, Dayan	1	86	17
	Wang, Wenling	1	86	17
	Wu, Guizhen	1	86	17
4	Yuen, kwok-yung	3	80	33
5	Chan, Jasper Fuk-woo	2	80	26
	Chu, Hin	2	80	26
	Kok, Kin-hang	2	80	26
	Kelvin, Kai-wang	2	80	26
	Yuan, Shuofeng	2	80	26

Table 3 Author list ranking by number of collaborators

Rank	Author	Number of papers	Times cited	Number of collaborators
1	Drosten, Christian	5	69	66
2	Akhmetzhanov, Andrei R.	7	18	57
	Linton, Natalie M.	7	18	57
	Nishiura, Hiroshi	7	18	57
3	Hayashi, Katsuma	6	18	55
	Jung, Sung-mok	6	18	55
	Kinoshita, Ryo	6	18	55
	Kobayashi, Tetsuro	6	18	55
	Yang, Yichi	6	18	55
4	Yuan, Baoyin	5	18	45
5	Hu, Yi	3	28	40

Table 4 Correlation Analysis

		Number of papers	Times cited
Number of collaborators	Pearson Correlation	.489**	.422**
	Sig. (2-tailed)	.000	.000
	N	1629	1629

**. Correlation is significant at the 0.01 level (2-tailed).

According to the above table, correlation analysis is used to study the correlation between times cited, number of papers and number of collaborators, respectively. The Pearson Correlation coefficient is used to represent the strength of the correlation.

Specific analysis shows that: The correlation value between times cited and number of collaborators is 0.569 and shows a significance level of 0.01, indicating that times cited and number of collaborators had a significant positive correlation. The correlation value between number of papers and number of collaborators is 0.860 and shows a significance level of 0.01, indicating that number of papers and number of collaborators have a significant positive correlation.

From the analysis above, it can be concluded that authors that focus on the COVID-19 and get a large number of collaborators may also get a larger number of papers and times cited. Collaboration benefit the productivity of scientific research on COVID-19. A secondary deduction is that Chinese authors collaborated actively during the outbreak of COVID-19 and Chinese research groups are connected with each other by the authors who served as the bridge (Figure 2). Most Chinese authors on the highly cited author list are in the role of a bridge in the network.

5. Journal Collaboration

When it comes to the journal network, many researchers have employed journal network analysis to paint a picture of scientific knowledge at various levels of view. In general, a journal network can be derived from either co-citation or citation analysis[3]. Academic interrelationships between journals can be determined based on citing-cited relationships between publications. The citing-cited relationships connect two journals and benefit the impact of both two, so it is journals' collaboration.

Citation Analysis

This study used Hiscite and VOSviewer to analyze journal collaboration based on the data of the 415 papers. Hiscite is used to count the number of papers published by a journal, Peer citations and WOS citation of source journals for 415 papers. The

Peer citation is the total number of citations of a journal cited by other journals, and these selected journals are the sources of 415 papers. WOS citation is the total number of citations of a journal cited by other journals in the Web of Science database. VOSviewer is used to analyze the citation and co-citation of journals. In Table 5, this study lists the top 10 journals with number of papers published, peer citation and WOS citation respectively. Through comparative analysis, it can be found that five journals, 《LANCET》, 《JOURNAL OF MEDICAL VIROLOGY》, 《EUROSURVEILLANCE》, 《NEW ENGLAND JOURNAL OF MEDICINE 》 and 《 RADIOLOGY 》 are in the top 10 in all three rankings. The number of papers published in 《 LANCET 》 ranked second, the number of peer citations and the number of WOS citations in 《 LANCET 》 ranked first, thus proving that this journal is the best journal in the industry.

Table 5 Journal ranking list

Rank	Journal	Number of papers published	Journal	Peer citation	Journal	WOS citation
1	BMJ-BRITISH MEDICAL JOURNAL	49	LANCET	334	LANCET	369
2	LANCET	37	NEW ENGLAND JOURNAL OF MEDICINE	140	NEW ENGLAND JOURNAL OF MEDICINE	158
3	JOURNAL OF MEDICAL VIROLOGY	23	JOURNAL OF MEDICAL VIROLOGY	42	NATURE	146
4	EUROSURVEILLANCE	22	EUROSURVEILLANCE	29	JOURNAL OF MEDICAL VIROLOGY	54
5	JOURNAL OF CLINICAL MEDICINE	13	RADIOLOGY	21	EUROSURVEILLANCE	44
6	INTENSIVE CARE MEDICINE	11	INTERNATIONAL JOURNAL OF INFECTIOUS DISEASES	19	JOURNAL OF CLINICAL MEDICINE	30
7	EMERGING MICROBES & INFECTIONS	9	CELL RESEARCH	14	INTERNATIONAL JOURNAL OF INFECTIOUS DISEASES	24
8	JOURNAL OF KOREAN MEDICAL SCIENCE	9	EMERGING MICROBES & INFECTIONS	14	BMJ-BRITISH MEDICAL JOURNAL	21
9	RADIOLOGY	9	SCIENCE CHINA-LIFE SCIENCES	12	RADIOLOGY	21
10	NATURE MEDICINE	7	BIOSCIENCE TRENDS	8	CELL RESEARCH	17
	NEW ENGLAND JOURNAL OF MEDICINE	7				

In scientific research, the occurrence of citation activities can be regarded as the knowledge transfer. This knowledge transfer takes place with a scholar's work is cited by others, thus using paper as the carrier to share such knowledge with other audiences. Knowledge transfer via paper times cited can be analyzed from the authors, papers and journals[16]. The citation relationship between journals reflects the knowledge transfer and scientific collaboration between journals. After importing the data from 415 papers into the VOSviewer in text format and selecting citation analysis, a total of 144 journals were identified, and the journals with no less than 3 published papers in our data set were selected. A total of 33 journals meet the above stated requirements.

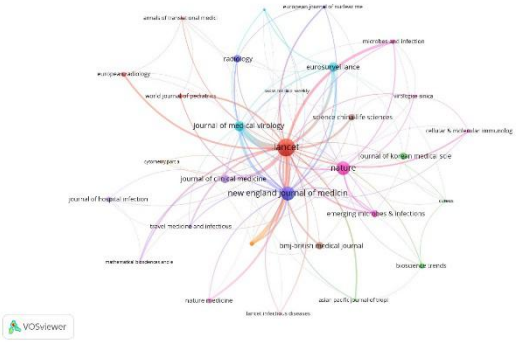

Figure 3 Journal citation map

Figure 3 shows the citation relationship between journals. Nodes represent journals. The node size represents the number of times cited in Web of Science database. The more citations between journals, the thicker the link between nodes. Nodes in Figure 3 represent that《LANCET》,《JOURNAL OF MEDICAL VIROLOGY》,《NATURE》,《NEW ENGLAND JOURNAL OF MEDICINE 》, and 《EUROSURVEILLANCE》are bigger than others. They have greater influence in the journal collaboration network and have been cited many times. 《LANCET》has the closest collaboration with 《 JOURNAL OF MEDICAL VIROLOGY 》, followed by 《 INTENSIVECAREMEDICINE 》, 《EUROSURVEILLANCE》, and 《JOURNAL OF CLINICAL MEDICINE》.

The link between《NEW ENGLAND JOURNAL OF MEDICINE》 and 《JOURNAL OF MEDICAL VIROLOGY 》 is also strong, reflecting a close collaborative relationship. Overall, 《LANCET》is at the core position of the journal collaboration network. It has a strong citation relationship and close collaboration with《NEW ENGLAND JOURNAL OF MEDICINE 》, 《 JOURNAL OF MEDICAL VIROLOGY》 and《EUROSURVEILLANCE》. Thirty-three journals form a collaborative network centered around these four positions. As described in Table 1, these four journals are ranked in the top 5 of peer citations and WOS citations, and links between these four journals are strong in Figure 1 which means they cited each other a lot. Considering the high numbers of papers published in these four journals (accounting for 22% of 415 papers), most citations they received are from each other. However, the node of《NATURE》is big in figure 1 because of its high WOS Citation but the links between 《NATURE》and other journals are weak due to its

low peer citation. Most journals who cite《NATURE》 are not medical journals so they may not show in Figure 3. High-impact journals as 《LANCET》 or 《NEW ENGLAND JOURNAL OF MEDICINE》 maintain their influence by citation relationship with each other.

Co-citation analysis

This study did a journal co-citation analysis based on the bibliometrics data of 415 papers. A high co-citation frequency between two journals implies a thick line between them. In previous studies[17-20], co-citation analysis has often been utilized to construct a journal network. It is said that two journals are co-cited when at least one article from each journal is listed in a citing article's reference list [18].A total of 1856 journals were cited in 415 papers, among which 45 journals were cited no less than 20 times. We used the VOSviewer to analyze the co-citation of these 45 journals and make a knowledge map of co-citation.

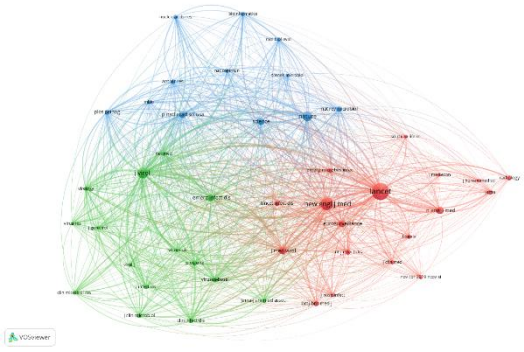

Figure 4 Journal co-citation map

In Figure 4, 45 journals were divided into three groups according to the co-citation relationship. The red group is represented by《LANCET》 and《NEW ENGLAND JOURNAL OF MEDICINE》, and most journals in the red group are comprehensive medical journals. The green group is represented by 《JOURNAL OF MEDICAL VIROLOGY》 and 《INTERNATIONAL JOURNAL OF INFECTIOUS DISEASES》, and most journals in the green group are of basic medicine, including nodes such as Virology, infection, and microbiology. The blue group can be represented by 《NATURE》 and 《SCIENCE》, and most journals in the blue group are multidisciplinary science journals.

6. Institutional collaboration

As collaboration has continued to increase, scholars have examined not only whether or not people are writing articles together, but if those individuals are employed by different institutions (Ali, Cassidy R, & Fereshteh, 2011)[10]. Mapping scientific collaboration at the institution level reveals that institutions cooperate in fighting pandemic and represent the core of the network. The core institutions produce the largest number of scientific papers of the world.

The map of institutional collaboration network was generated on the basis of 415 papers by the VOSviewer. As shown in Figure 5, each node represents the scientific research institution; the size of the node represents the number of papers published by the institution, the thickness of the line represents the collaboration frequency, and the color of the node represents different clusters. We also ranked the institutes by the number of papers published of the research on COVID-19 within 3 months following the initial outbreak (Jan 1st–Apr 1st). We ranked institutes by the number of papers they published in the 3 months in Table 6 and found that most institutions in top 10 institutions are Chinese institutes, with the Chinese Academy of Sciences at the top, Huazhong University of Science& Technology at the second, and Wuhan University and Fudan University at the third place respectively. Comparing the number of papers published, times cited and institutional collaborators, it can be found that the collaboration between institutes benefits scientific productivity, increasing the influence of institutions.

Table 6 Institution list ranking by the number of papers published

Rank	University	Number of papers published	Times cited	Number of collaborators
1	Chinese Acad Sci	20	328	17
2	Huazhong Univ Sci & Technology	18	167	23
3	Wuhan Univ	15	154	21
	Fudan Univ	15	53	13
4	Univ Hong Kong	14	142	9
5	Capital Med Univ	13	237	26
6	Guangzhou Med Univ	12	16	13
7	Peking Univ	9	24	19
	Zhejiang Univ	9	6	14
8	Shang Hai Jiao Tong Univ	8	69	10
	Hokkaido Univ	8	18	8
	Sun Yat Sen Univ	8	25	8
9	Univ Sydney	8	65	5
10	Chinese Acad Med Sci	7	149	11

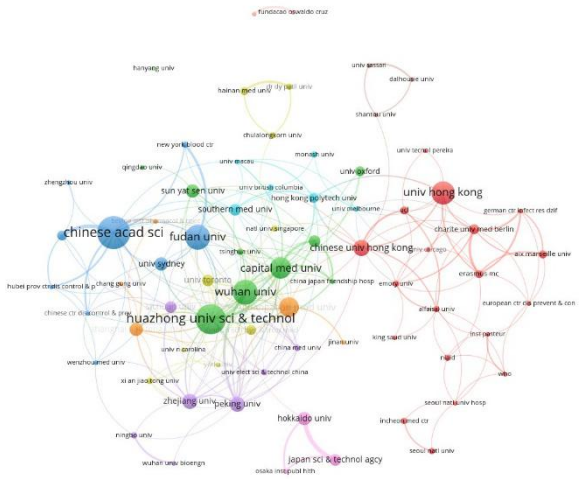

Figure 5: Institutional collaborative map

A total of 70 institutions with more than 3 papers published were selected for the research. We used VOSviewer to analyze the strength of collaboration among various scientific research institutions and 70 institutions were divided into 10 clusters. As shown in Figure 5, there are four big cluster in the map. The red cluster's core institutions are Chinese University Hong Kong and University Hong Kong; the green cluster's core institutions are Huazhong University Sci & Technol and Wuhan University; the blue cluster's core institutions are Chinese Academy of Sciences; the purple cluster's core institutions are Peking University and Zhejiang University.

The specific institutions of collaborative clusters are shown in Table 7. As shown in Figure 5 and Table 6, the institutional collaboration on the research of COVID-19 within 3 months following the initial outbreak has the following three characteristics: (1) Regionalization: institutions in the same region are more inclined to collaborate with each other. For example, Huazhong University of Science and Technology in Hubei Province and Wuhan University in the same region have a close collaborative relationship. (2) Internationalization: institutions of various countries tend to collaborate with each other across borders. As can be seen from Figure 5 and Table 6, institutions of China, the United States, the United Kingdom and other countries conducted close scientific research collaboration after the COVID-19 outbreak. (3) Diversification: in the process of collaboration between institutions, different types of institutions such as government departments, hospitals, universities launched close scientific research collaboration to speed up the completion of scientific research. In addition, in the process of collaboration, there are both direct and indirect collaborative relations. For example, the University of Sydney has direct collaborative relations with the World Health Organization and Fudan University, and has indirect collaborative relations with the University of Hong Kong through these direct collaborative institutions.

Table 7: Clusters of institutional collaboration

Cluster	Institute
C1	Aix Marseille University; Alfaisal University; Charite University Med Berlin; Chinese University Hong Kong; Emory University; Erasmus Mc; The European Centre For Disease Prevention And Control; German Center For Infection Research; Incheon Medical Center; Inst Pasteur; King Saud University; Niaid; Seoul Natl University; Seoul Natl University Hosp; Ucl; University Chicago; University Hong Kong; University Technology Pereira; WHO;
C2	Capital Med University; China Japan Friendship Hosp; Chinese Acad Med Sci; Huazhong University Sci & Technol; Qingdao University; Sun Yat Sen University; Tsinghua University; University Oxford; Wuhan University;
C3	Chinese Academy of Sciences; Chinese Center for Disease Control and Prevention; Fudan University; Hubei Provincial Center For Disease Control And Prevention; New York Blood Ctr; University Chinese Academy Sci; University Sydney; Wenzhou Med University; Zhengzhou University;
C4	Chulalongkorn University; Dr Dy Patil University; Hainan Med University; The London School Of Hygiene & Tropical Medicine; Natl University Singapore; University N Carolina; University Toronto; Xi An Jiao Tong University; York University;
C5	China Med University; Ningbo University; Peking University; Sichuan University; University Elect Sci & Technol China; Wuhan University; Bioengn; Zhejiang University;
C6	Hong Kong Polytech University; Monash University; Southern Med University; University British Columbia; University Macau; University Melbourne;
C7	Beijing Inst Pharmacol & Toxic; Chang Gung University; Guangzhou Med University; Jinan University; Shanghai Jiao Tong University;
C8	Dalhousie University; Shantou University; University Sassari;
C9	Hokkaido University; Japan Sci & Tech Agency; Osaka Inst Public Health;
C10	Fundacao Oswaldo Cruz; University Campus Biomed;

7. International Collaborations by Country

Mapping scientific collaboration on research of COVID-19 within the 3 months following the initial outbreak at the country level reveals that countries cooperate in fighting pandemic and represent the core of the network. The core countries are producing the largest number of scientific papers of the world.

This study used VOSviewer to map the network of scientific research collaboration based on the co-authored papers of researchers from various countries. These co-authored papers were selected from the 415 papers. As shown in Figure 6, the size of a node in Figure implies the number of papers published by a country; the link between two countries implies the collaboration between researchers of two countries and the thickness of a link between two countries in network diagram is

depend on the frequency of collaboration between them. As can be seen from the Figure 6, the nodes of China and the United States are larger, which proves that these two countries published most papers of 415 papers, and the link between China and the United States is the thickest, which proves that the two countries have the most frequent and closest scientific research collaboration. The nodes of China and the United States occupy the core position of the connection in the network and are the major collaboration partners of countries around the world.

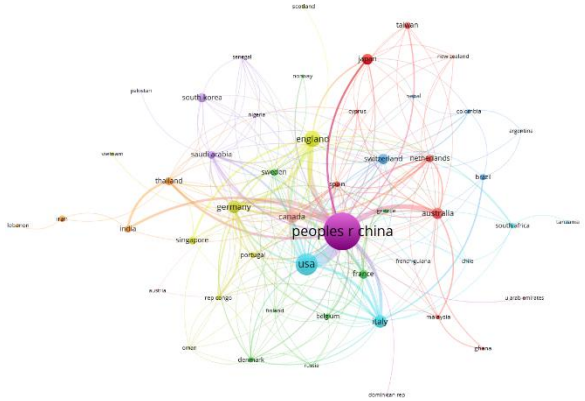

Figure 6: Map of research collaboration among countries of the world

We also ranked countries according to the number of publications in table 8. The top 10 countries are shown in the table below. Comparing Figure 6, it can be found that all the top ten countries except Italy and South Korea have collaborated with China in the study of COVID-19.

Table 8 Country list ranking by the number of papers published

Rank	Country	Number of papers published	Times cited	Times of collaboration
1	Peoples R China	182	798	111
2	USA	65	147	69
3	England	36	80	53
4	Germany	23	76	47
5	Canada	22	14	39
6	Italy	22	28	38
7	Australia	17	68	28
8	Switzerland	15	13	17
9	Japan	13	18	11
10	South Korea	12	21	8

Figure 7 shows the network of countries that have scientific collaboration with China. China has the highest frequency of scientific research collaboration and the closest collaborative relationship with the Western developed countries as United States, the United Kingdom, Canada, Germany and Sweden, Belgium, Denmark, Portugal, and Spain. During the pandemic period, researchers from these countries jointly worked on COVID-19 research and formed a strong collaborative relationship. In Asia, primary collaborators of China include Japan, India, Thailand, Singapore, and Malaysia. In Oceania and Africa, China collaborate with Australia and Congo. Compared with Table 8, it can be seen that all of the countries in top 10 have collaborated with China except South Korea. Figure 8 shows the network of collaborators with the United States. The United States and China have the highest frequency of scientific research collaboration and the closest collaborative relationship. In addition to China, the United States also has a high frequency of collaboration with England, Canada, Italy, Australia, France, Japan, Germany, Switzerland and South Korea. All of the countries in the top 10 have collaborated with America. It can be concluded that top 10 countries of the world have a tendency toward multinational team workings. However, there are some countries which are represented by the dark and small nodes in Figure 7 and Figure 8 did not conduct scientific research collaboration with China nor America. These countries may have formed their own scientific research collaboration groups, but they only have few collaborators.

From the analysis above, we conclude as follows: Firstly, China received the largest number of papers published, times cited and times of collaborator in the first three month of the pandemic, followed by the United States and other western countries. Secondly, the productive countries tend to cooperate with other productive one to maintain their productivity or influence in the domain. The majority of strong links in Figure 5 are between big nodes such as China and America, China and Australia, China and England, America and England and so on. The world has formed a scientific research collaboration network centered on China and the United States.

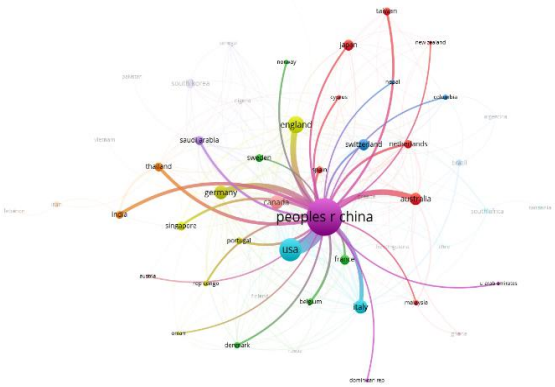

Figure 7: Collaboration network with China

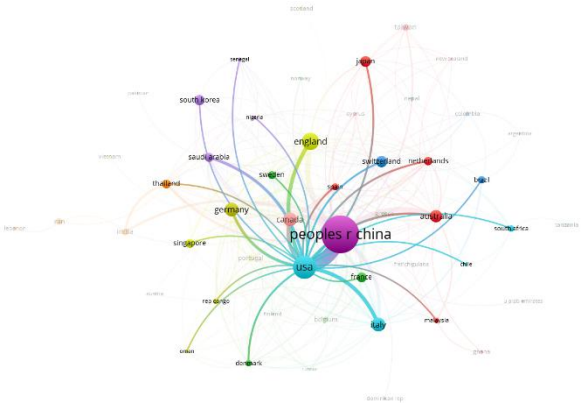

Figure 8: Collaboration network with the United States

8. Discussion

The objective of this study was to provide a global description of collaboration behaviors across multiple collaboration types including authors, journals, institutions and Countries within the three months following the initial outbreak of COVID-19. The data of 415 papers, these scientific achievements, were provided by the scholars who were working together to combat the pandemic from Jan 1st, 2020 to Apr 1st, 2020. They showed the efficient scientific work response to the international public health emergency and the power of scientific collaboration. In this study, collaborative behavior to combat the pandemic is not only at the author level, but at the journal, the institution and country level. Scientific world has tendency toward multi-authored, multi-institutional, and multi-national team workings to meet the international public health emergency.

Conclusion

The main findings of this study are as follows: Researchers in the field of medicine have been collaborating around the world to fight the COVID-19. The world has formed a scientific research collaboration network centered on China and the United States. Most of the top 10 countries in scientific productivity during pandemic period have collaborated with China. China made the most important scientific contribution at the first three months of outbreak, and the most influential authors and productive institutions are Chinese. Institutional collaboration reveals three characteristics of collaboration during the pandemic: regionalization, internationalization and diversification. The top 5 influential journals during the pandemic are 《 LANCET 》 , 《 JOURNAL OF MEDICAL VIROLOGY》 ,《NATURE》 ,《NEW ENGLAND JOURNAL OF MEDICINE 》 , and 《 EUROSURVEILLANCE 》 . These top journals produced closer collaboration due to frequently citing with one another.

Limitation and Future Research

Although this study has presented the global collaboration on the research of COVID-19 across different levels, there were some limitations.

Firstly, the data sample is small. We conducted this research in 415 papers published in the first three months of the COVID-19. Both the timespan and size of data is limited. The structure of collaboration and the ranks of authors, journals, institutions and countries are changing all the time. As such, future research is needed to expand the scope of data collection and extend the timespan to 1 year at least. We may use attribute weighted naive bayes to evaluate contributions of authors, journals, institutions and countries[21].

Secondly, this study is exploratory and descriptive. We mainly relied on bibliometrics network visualization to provide a knowledge map of collaboration but didn't explain the various reasons behind the collaborations in different levels. The technology of knowledge maps' classification can be applied in future research[22, 23]. Collaborations between individual researchers can be explained with various reasons, collaboration at the institutional level indicates strategic decision-making. The clusters are revealed in this study, and it would be most interesting to know the reasons and rationale behind the structure. Future studies could use multiple methods to examine the reasons behind the clusters.

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